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FOR

WRITE POLE FABRICATION FOR PERPENDICULAR RECORDING

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WRITE POLE FABRICATION FOR PERPENDICULAR RECORDING

FIELD OF THE INVENTION

The present invention relates to magnetic heads, and more particularly, this invention relates to fabrication of a head having a trailing shield structure.

BACKGROUND OF THE INVENTION

In a typical head, an inductive write head includes a coil layer embedded in first, second and third insulation layers (insulation stack), the insulation stack being located between first and second pole piece layers. A gap is formed between the first and second pole piece layers by a gap layer at an air bearing surface (ABS) of the write head. The pole piece layers are connected at a back gap. Currents are conducted through the coil layer, which produce magnetic fields in the pole pieces. The magnetic fields fringe across the gap at the ABS for the purpose of writing bits of magnetic field information in tracks on moving media, such as in circular tracks on a rotating magnetic disk or longitudinal tracks on a moving magnetic tape.

The second pole piece layer has a pole tip portion which extends from the ABS to a flare point and a yoke portion which extends from the flare point to the back gap. The flare point is where the second pole piece begins to widen (flare) to form the yoke. The

placement of the flare point directly affects the magnitude of the magnetic field produced to write information on the recording medium. Since magnetic flux decays as it travels down the length of the narrow second pole tip, shortening the second pole tip will increase the flux reaching the recording media. Therefore, performance can be optimized by aggressively placing the flare point close to the ABS.

FIG. **1A** illustrates, schematically, a conventional recording medium such as used with conventional magnetic disc recording systems. This medium is utilized for recording magnetic impulses in or parallel to the plane of the medium itself. The recording medium, a recording disc in this instance, comprises basically a supporting substrate **100** of a suitable non-magnetic material such as glass, with an overlying coating **102** of a suitable and conventional magnetic layer.

FIG. **1B** shows the operative relationship between a conventional recording/playback head **104**, which may preferably be a thin film head, and a conventional recording medium, such as that of FIG. **1A**.

As longitudinal recording is expected to reach its maximum at about ~140Gbit/in^2 due to the superparamagnetic effect, efforts have been focused on perpendicular recording to extend areal density.

FIG. **2A** illustrates schematically the orientation of magnetic impulses substantially perpendicular to the surface of the recording medium. For such perpendicular recording the medium includes an under layer **302** of a material having a high magnetic permeability. This under layer **302** is then provided with an overlying coating **304** of magnetic material preferably having a high coercivity relative to the under layer **302**.

Two embodiments of storage systems with perpendicular heads **300** are illustrated in FIGS. **2A** and **2B** (not drawn to scale). The recording medium illustrated in FIG. **2B** includes both the high permeability under layer **302** and the overlying coating **304** of magnetic material described with respect to FIG. **2A** above. However, both of these layers **302** and **304** are shown applied to a suitable substrate **306**.

By this structure the magnetic lines of flux extending between the poles of the recording head loop into and out of the outer surface of the recording medium coating with the high permeability under layer of the recording medium causing the lines of flux to pass through the coating in a direction generally perpendicular to the surface of the medium to record information in the magnetically hard coating of the medium in the form of magnetic impulses having their axes of magnetization substantially perpendicular to the surface of the medium. The flux is channeled by the soft underlying coating **302** back to the return layer (P1) of the head **300**.

FIG. **2C** illustrates a similar structure in which the substrate **306** carries the layers **302** and **304** on each of its two opposed sides, with suitable recording heads **300** positioned adjacent the outer surface of the magnetic coating **304** on each side of the medium.

One area of research in perpendicular head design is focused on developing a manufacturable fabrication process to form the write pole. Unlike longitudinal head design whereby the write pole aspect ratio is ~4:1, perpendicular write pole design requires a 2:1 aspect ratio and ~15 degree bevel to minimize adjacent track interference. As areal density approaches 120 Gb/in^2 or higher, the write pole's trackwidth scales down to 140 nm or lower. At these dimensions, write pole instability (reminiscent issues,

e.g., writing continuing after power to head is terminated) becomes an issue and requires implementing lamination technology in the write pole. Lamination, however, forecloses use of plating to form the write pole.

In the fabrication aspect, factors such as HSU, shield thickness from the air bearing surface (ABS), and gap controls are important in achieving the angling effect of the effective write field. During fabrication, the gap must be tightly controlled. In slider lapping, the shield thickness from the ABS must be precisely controlled. The parameters presented below must be considered to achieve optimal effective write field.

The constant demand for higher areal density has aggressively pushed for narrower trackwidth. Since the perpendicular write pole's aspect ratio is 2:1 and as the write pole trackwidth approaches ~102 nm for 200Gbit/in^2 areal density, the thickness of the write pole will be about the thickness of a typical seed-layer. The difficulty in fabricating a trailing shield write pole is designing a process to have tight control of the write gap and fabricating a structure on top of the write gap with minimal damage to the write gap or write pole. Precise control of the gap thickness is important because if the gap is too thin, too much flux goes to the shield. If the gap is too thick, the flux angle into the media is not desirable, as the flux is most effective when entering the media at an angle (e.g., 45°) with respect to disk surface. Thus, the gap thickness must be near perfect.

The improvements of the single pole trailing shield (SPT) design of the invention over the single pole (SP) design can be explained by the Stoner-Wohlfarth model. FIG. **3** is a plot of H-grain angle as a function of the main grain angle. It can be seen that for a distribution of grain angles, increasing the angle between H and the mean grain angle can

decrease the distribution of switching fields by 1/2 thus increasing the effective field by 2X and decreasing jitter.

FIG. **4** is a partial side view of a writer **400**. The optimal field angle is achieved in the design when the distance (**HSU**) from the ABS to the soft underlayer of the media **402** is equal to the length of the write gap (**GAP**), which is the distance between the end of the trailing shield **404** and the write pole **406**. The write field is decreased as the shield **404** is brought closer to the write pole piece **406** because part of the flux is increasingly shared between the soft underlayer of the media **402** and the trailing shield **404**. This problem is ameliorated by controlling the thickness of the trailing shield **404**, **GAP**, **HSU**, and bringing the flare point of the write pole closer to the ABS.

To get the optimized effective field angle, the gap and shield thickness need to be tightly control as shown in FIG. **5**.

The benefits provided by such a design include:

1) Increased dH/dX
2) Reduced partial erasure
3) Improved saturation
4) Reduced media noise
5) Tilt field eases writing on S-W media.

In the past, damascene and image transfer technologies (DITT) were considered as methods to form the 15 degree beveled 2:1 aspect ratio of the write pole. However, due to the need to implement lamination to reduce write instability these technologies were found to be undesirable.

Ion milling is emerging as an alternative approach to DITT to fabricate laminated write poles, but is not directly extendable to a trailing shield write pole design whereby the gap thickness between the write pole and shield (trailing shield) is tightly controlled.

Moreover at submicron trackwidth dimension, the pole piece as fabricated by ion milling will be fragile and removal of redeposited materials on top (redeposition) and sides (fencing) of the pole will be increasingly more difficult.

What is needed is an effective and reliable way to fabricate a laminated write pole and write gap of a precise thickness for use in a perpendicular recording head.

The present invention introduces a method and materials to fabricate a trailing shield write pole that resolve the problems of controlling the write gap and preventing damage to the write gap or pole during fabrication of the subsequent structure. This process also introduces a CMP assisted lift-off process to remove redeposition and fencing (to increase yields) and a method to create curvature in the write pole.

SUMMARY OF THE INVENTION

The present invention provides the desired benefits described above by providing a method for forming standard and thin film magnetic head structures for recording and reading, and that is particularly adapted to perpendicular recording and reading. One method for forming a head structure having an air bearing surface (ABS) includes forming a flux shaping layer and forming a pole tip layer on the shaping layer, the shaping layer being for focusing flux to the pole tip layer. Preferably, the pole tip layer is laminated.

A mask layer is formed above the pole tip layer, the mask layer being more resistant to milling than the pole tip layer so that it functions as a milling hard mask and as a CMP stop layer. The mask layer can be patterned by image transferring a resist imaging layer into the mask layer by reactive ion etching (RIE). The mask layer is preferably formed of a material selected from a group consisting of carbon, a silicon nitrate, a tantalum oxide, and a silicon oxide. Most preferred materials are carbon formed by filtered cathodic arc (FCA) deposition, Si_3N_4, Ta_2O_5, and SiO_2.

A layer of resist is formed above the mask layer and patterned, the patterned resist defining about a maximum width of the pole tip in a direction parallel to the ABS of the head. Portions of the mask layer not covered by the patterned resist are removed, preferably by reactive ion etching.

Milling is performed for shaping a pole tip from the pole tip layer. Preferably, the pole tip layer is shaped to taper together towards the shaping layer along a plane perpendicular to the ABS.

A layer of dielectric material is deposited above the (material covering the) pole tip and flux shaping layer, where the layer of dielectric material extends about adjacent to the mask layer. Preferably, the mask layer is comprised of a bilayer of durimide and carbon collectively functioning as the mask layer. This increases the overall thickness of the mask layer and its ion mill resistance. When the dielectric material is deposited, it should abut the carbon layer which functions as a CMP stop layer. A stop layer is deposited over the dielectric material, the stop layer abutting the mask layer.

Polishing is performed for forming a substantially planar upper surface consisting of the mask layer and stop layer. The polishing also removes redeposited material, allowing formation of the gap layer to a finely-controlled thickness. Preferably, the polishing is chemical mechanical polishing with a slurry selective to the dielectric material.

As an optional step, the mask layer may be removed prior to forming the gap layer, and dishing formed in the upper surface of the pole tip. It has surprisingly been found that a little dishing into the pole tip straightens out the transition field. The extent of dishing also aids in creation of the gap thickness. The mask layer can be removed by additional polishing or etching (e.g., reactive ion etching). The dishing can be formed by etching (e.g., sputter etching) or by polishing.

The gap layer is formed above the pole tip to a desired thickness, and a trailing shield is formed above the gap layer. A return pole is formed above the trailing shield. In

one embodiment, a coil structure is formed behind the trailing shield with respect to the ABS.

Other aspects and advantages of the present invention will become apparent from the following detailed description, which, when taken in conjunction with the drawings, illustrate by way of example the principles of the invention

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the nature and advantages of the present invention, as well as the preferred mode of use, reference should be made to the following detailed description read in conjunction with the accompanying drawings.

FIG. **1A** is a schematic representation in section of a recording medium utilizing a longitudinal recording format.

FIG. **1B** is a schematic representation of a conventional magnetic recording head and recording medium combination for longitudinal recording as in FIG. **1A**.

FIG. **2A** is a magnetic recording medium utilizing a perpendicular recording format.

FIG. **2B** is a schematic representation of a recording head and recording medium combination for perpendicular recording on one side.

FIG. **2C** is a schematic representation of the recording apparatus of the present invention, similar to that of FIG. **2B**, but adapted for recording separately on both sides of the medium.

FIG. **3** is a plot of H-grain angle as a function of the main grain angle.

FIG. **4** is a partial side view of a writer.

FIG. **5** is a partial side view of a writer.

FIG. **6** is a simplified drawing of a magnetic recording disk drive system.

FIG. **7** is a simplified schematic representation of the improved recording apparatus of the present invention illustrating a recording head and recording medium combination for perpendicular recording on one side.

FIGS. **8A-8I** depict a process for forming a trailing shield write pole structure for a perpendicular head according to one embodiment.

FIG. **8J** illustrates a micromagnetic simulation showing curved transitions at the P3.

FIG **9** is a cross-sectional view of a typical head, not to scale, formed according to the process described in FIGS. **8A-8I.**

FIG. **10** is a side cross sectional view of a perpendicular read/write head structure, not to scale, according to one embodiment of the present invention.

FIG. **11** is a partial side view of a perpendicular write head pole tip region, not to scale, during fabrication of a write head.

FIG. **12** is a partial side view of the perpendicular write head pole tip region of FIG. **11** upon addition of a trailing shield by deposition.

FIG. **13** is a partial side view of the perpendicular write head pole tip region of FIG. **11** upon addition of a trailing shield by plating.

FIG. **14** is a partial side view of the perpendicular write head pole tip region of FIG. **13** upon addition of a return layer.

Best Mode for Carrying Out the Invention

The following description is the best embodiment presently contemplated for carrying out the present invention. This description is made for the purpose of illustrating the general principles of the present invention and is not meant to limit the inventive concepts claimed herein.

Referring now to FIG. **6**, there is shown a disk drive **600** embodying the present invention. As shown in FIG. **6**, at least one rotatable magnetic disk **612** is supported on a spindle **614** and rotated by a disk drive motor **618**. The magnetic recording on each disk is in the form of an annular pattern of concentric data tracks (not shown) on the disk **612**.

At least one slider **613** is positioned near the disk **612**, each slider **613** supporting one or more magnetic read/write heads **621**. More information regarding such heads **621** will be set forth hereinafter during reference to the remaining FIGS. As the disks rotate, slider **613** is moved radially in and out over disk surface **622** so that heads **621** may access different tracks of the disk where desired data are recorded. Each slider **613** is attached to an actuator arm **619** by way of a suspension **615**. The suspension **615** provides a slight spring force which biases slider **613** against the disk surface **622**. Each actuator arm **619** is attached to an actuator means **627**. The actuator means **627** as shown in FIG. **3** may be a voice coil motor (VCM). The VCM comprises a coil movable within a fixed magnetic field, the direction and speed of the coil movements being controlled by the motor current signals supplied by controller **629**.

During operation of the disk storage system, the rotation of disk **612** generates an air bearing between slider **613** and disk surface **622** which exerts an upward force or lift on the slider. The air bearing thus counter-balances the slight spring force of suspension **615** and supports slider **613** off and slightly above the disk surface by a small, substantially constant spacing during normal operation.

The various components of the disk storage system are controlled in operation by control signals generated by control unit **629**, such as access control signals and internal clock signals. Typically, control unit **629** comprises logic control circuits, storage means and a microprocessor. The control unit **629** generates control signals to control various system operations such as drive motor control signals on line **623** and head position and seek control signals on line **628**. The control signals on line **628** provide the desired current profiles to optimally move and position slider **613** to the desired data track on disk **612**. Read and write signals are communicated to and from read/write heads **621** by way of recording channel **625**.

The above description of a typical magnetic disk storage system, and the accompanying illustration of FIG. **6** are for representation purposes only. It should be apparent that disk storage systems may contain a large number of disks and actuators, and each actuator may support a number of sliders.

FIG. **7** illustrates schematically the orientation of magnetic impulses off-normal to an imaginary plane oriented perpendicular to the surface of the recording medium, generally in the manner provided for by the present invention. It is advantageous to write transitions to the media at an off-normal axis produces more stable domains in the media, as described in N.H. Yeh, J. Magn. Soc. Jpn., v. 21, p. 269 (1997), which is herein

incorporated by reference. The off-normal flux is created by the combination of a pole **702** and a trailing shield **703**.

Similar to the structure recited above with respect to FIG. **3**, the medium includes an under layer **704** of a material having a high magnetic permeability, preferably greater than 100, such as a permalloy material. This under layer **704** is then provided with an overlying coating **706** which contains a magnetic material preferably having a coercivity substantially greater than the under layer **704**. Both of these layers **704** and **706** are shown applied to a suitable substrate **708,** which may desirably be an aluminum alloy disc, although other material such as glass may also be used.

Magnetic lines of flux extending between the poles **702, 710** of the recording head **700** loop into and out of the outer surface of the recording medium coating **706** with the high permeability under layer **704** of the recording medium causing the lines of flux to pass through the coating **706** in a direction at an angle to an imaginary plane perpendicular to the surface of the medium to record information in the magnetically hard coating **706** of the medium in the form of magnetic impulses having their axes of magnetization generally perpendicular to the surface of the medium. The flux is channeled by the soft underlying coating **704** back to the return layer (P1) **710** of the head **700**.

As mentioned above, the need for higher areal density has aggressively pushed for narrower trackwidth. Since the perpendicular write pole tip's aspect ratio is about 2:1 and as the pole size approaches ~102 nm for 200Gbit/in^2 areal density, the thickness of the write pole tip will be about the thickness of a typical seed-layer. The difficulty in fabricating a trailing shield write pole tip is designing a process to have tight control of

the write gap and fabricating a structure on top of the write gap with minimal damage to the write gap or write pole tip.

The present invention introduces a method and materials to fabricate a trailing shield write pole structure that resolve the problems of controlling the write gap and preventing damages to the write gap or pole during fabrication of the subsequent structure. This process also introduces CMP assisted lift-off process to remove re-deposition and fencing (increase yields) and a method to create curvature write pole. Moreover, also included in this disclosure are suitable materials that can function as an ion mill transfer layer, CMP layer, and RIEable layer. Note that the processes described herein are equally applicable to fabrication of single pole designs without trailing shields as well.

One approach to fabricate the trailing shield write pole is to use a highly mill-resistant transfer layer to protect the trailing edge structure definition (TED) during milling that can also function as a CMP stop layer after alumina deposition to remove redeposition and fencing and later be removed cleanly by reactive ion etching (RIE) to deposit the write gap and form the trailing shield.

FIGS. **8A-8I** together illustrate a process for forming a trailing shield write pole structure for a perpendicular head.

FIG. **8A** illustrates an ABS view of a flux shaping layer **802** and a laminated pole tip layer **804** formed full film on top of the flux shaping layer **802**. The flux shaping layer **802** carries flux to the pole tip. The flux shaping layer **802** is recessed from the ABS so that it does not write to the media.

The flux shaping layer **802** is formed of a magnetic material such as $Ni_{45}Fe_{55}$, etc. The pole tip layer **804** is preferably a lamination of layers of magnetic (e.g., CoFe, $Ni_{22}Fe_{78}$, AlFeN, CoFe/NiFe, etc.) and nonmagnetic (e.g., Rh, Ru, Cr or other metal as well as nonconductive materials) layers. Because the pole tip layer **804** is laminated, it is will have to be milled (dry process), as it would be hard or impossible to plate a laminated stack, though the present invention does not foreclose this possibility.

With continued reference to FIG. **8A**, a mask layer **806** is formed above the pole tip layer **804**. The mask layer **806** is formed of any RIEable material that is resistant to milling. Preferred materials from which the mask layer **806** can be formed include carbon, silicon nitrates (e.g., Si_3N_4), tantalum oxides (e.g., Ta_2O_5), silicon oxides (e.g., SiO_2), durimide, etc. and combinations thereof. The most preferred material is carbon formed by filtered cathodic arc (FCA) deposition. The mask layer **806** constructed of these materials provides several functions. First, it functions as a mill hard mask, and preferably has a milling resistance greater than the resist (discussed below). The mask layer **806** also functions as a CMP stop layer as described below.

A preferred mask layer **806** is a multilayer film. The preferred embodiment of the mask layer **806** is a bilayer of carbon and durimide, with the carbon layer being positioned closest to the pole tip layer. Both materials function as an ion mill mask, but carbon also functions as the CMP stop layer. Use of durimide in combination with carbon significantly increases the thickness of the mask layer , which enhances the milling resistance of the mask layer to pattern the pole tip layer **804**.

A photoresist layer **808** is formed on the mask layer **806** and patterned using lithography to define a width of the write pole that will be formed from the write pole

layer **804**. Note that the width of the write pole should be a little wider than the final target width. This is because as the structure is ion milled to form the pole, the bevel is also formed. The beveling process will decrease the width of the pole.

A preferred resist is highly resistant to RIE chemistries to achieve higher selectivity to the mask layer **806**. For example, the resist should be resistant toward oxygen (O2) or carbon-oxygen (CO2) RIE chemistries such as silicon-containing resist. It is desirable for the RIE chemistry to have higher selectivity to durimide and carbon compared to the resist. The resist is used to pattern durimide and carbon. One major reason to add durimide into the film stack is to provide more milling resistance when forming the pole. To reduce the overall thickness of the structure, it may be undesirable to deposit thicker carbon for increasing ion milling resistance, so durimide can be added. Durimide is very resistant to milling as well as easy to apply to the structure.

As shown in FIG. **8B**, the mask layer **806** is etched by RIE to pattern the mask layer **806** to conform to the profile of the resist layer **808**. The mask layer **806** now functions as a hard mask.

Milling is performed at high incidence to form straight edges in the pole tip layer **804**. Then, as shown in FIG. **8C**, the structure is milled at an angle to create the beveled shape of the pole tip **810**, preferably at an angle of about 15% relative to the perpendicular. Fencing and redeposition can be removed by sweep milling at razing incidence.

Note that several alternative ion mill schemes may also be used, such as:

1. Thick alumina hard mask approach whereby the alumina hard mask is patterned with reactive ion etching (RIE) and BCI3 chemistry. The hard mask is then used to create a 15 deg beveled write pole into the high moment material by ion milling.
2. Trim-notch-trim like approach whereby a NiFe hard mask is formed by through mask plating and used to pattern high moment material by ion milling.

The trim-notch milling process as discussed above will leave the hard mask intact after write pole fabrication by substituting the NiFe hard mask with a non-magnetic material such as NiP, which is acceptable for a perpendicular single pole design.

Now that the pole tip **810** has been formed, further processing is conducted to form a write gap of precise thickness. Referring to FIG. **8D**, a layer of dielectric material **812** is deposited full film. A preferred dielectric material is alumina or some nonconductive metal. The dielectric material **812** is deposited to a level preferably abutting the mask layer **806**. If the mask layer **806** is a two layer film of carbon and duramide, the dielectric material **812** is filled to the carbon layer that functions as the CMP stop layer.

Endpoint or deposition rate can be used to determine where to stop deposition. Note that the dielectric material **812** supports the pole tip **810** for further processing (e.g., polishing), and also protects the pole tip **810** from corrosion.

As shown in FIG. **8E**, a stop layer **814** is deposited such that it matches up with the mask layer **806** on the pole tip **810**. Preferred materials from which the stop layer **814** may be constructed are the same materials used to form the mask layer **806**, though the

materials of the stop and mask layers do not have to be the same in any particular implementation.

Referring to FIG. **8F**, chemical mechanical polishing (CMP) is performed to planarize the structure. Preferably, a slurry is selected that is selective to alumina (the preferred dielectric material), i.e., that will polish alumina very easily but doesn't polish the mask and stop layer **814** material(s) as fast. The protruding portion of the structure is removed quickly, and polishing becomes slower when the mask and stop layers are reached. Thus, the mask layer **806** also functions as a CMP stop layer **814**, reducing the chance of overpolishing unless that is desired. The CMP step also removes any redeposited material and fencing adhering to the structure.

As shown in FIG. **8G**, the mask and stop layers are preferably removed and dishing **816** formed in the pole tip **810**. It has surprisingly been found that a little dishing into the pole straightens out the transition field. More particularly, the write field transition can be corrected by extending the CMP time to create dishing. Note FIG. **8J**, which depicts a magnetic simulation showing curved transitions **850** at the P3 width (PW3) of 120 nm. The extent of dishing also aids in creation of the gap thickness. Additional polishing can be performed to remove the mask and stop layers and create dishing **816** into the pole tip **810**. The mask and stop layers can also be removed by RIE. The dishing **816** is preferably formed by sputter etching, as alumina is resistant to sputter etching and therefore will not be significantly altered.

Now, because the pole tip **810** is exposed, it is possible to precisely control the thickness of the gap layer by simply depositing a gap layer **818** to the desired thickness, as shown in FIG. **8H**. The gap layer **818** between the pole tip **810** and trailing shield must

be nonmagnetic, e.g., of alumina or some metal such as Rh, Ru, etc. Rh and Ru are preferred because they are very conductive, and the oxide of Ru is electrically conductive so it can be plated on. If a metal gap is implemented, it can be used to plate up the trailing shield aspect of the head design, such as shield **820** of FIG. **9**. This method eliminates the problems found in prior art processes, namely that of redeposited material forming on top of the pole tip **810**, which affected the thickness of the write gap. Thus, the gap layer is left intact and provides a planar surface upon which to fabricate the trailing shield and back gap.

As depicted in FIG. **8I**, a trailing shield **820** is formed above the gap layer **818**. The trailing shield **820** is preferably constructed of a soft magnetic material, and should have a high magnetic moment. A preferred material for the trailing shield **820** is NiFe, CoFe, CoNiFe, and alloys thereof. A coil structure and insulation (not shown) are also formed. Finally, a return pole **822** is formed. Methods for forming the trailing shield **820**, coils, and return pole **822** are described below.

FIG **9** illustrates a typical head **900** in which the trailing shield write pole formed according to the process described above may be implemented. Also shown are coils **902** and insulation **904**, and a read head **906** that may be formed above or below the write head **908**.

FIG. **10** illustrates a perpendicular read/write head structure **1000** having a trailing shield **1002** according to another embodiment. Methods for forming the trailing shield will be discussed subsequently.

As shown in FIG. **10**, a residual masking structure **1004** can be created and left in the head **1000** to allow for the formation of the trailing shield and for the subsequent

fabrication steps to build the remainder of the write head **1006**. Note that it is desirable to leave the masking structure **1004** in the head **1000** to protect the write gap and pole tip, to protect them from subsequent processing (e.g., copper coils).

In this embodiment, a read head **1008** is formed first. The read head includes a first shield layer **1010**, a sensor **1012**, and a second shield layer **1014**. A pole **1016** is formed above the first shield layer **1010**. A coil structure **1018** and insulation layers **1020**, **1080** are formed above the first pole layer **1016**. A flux shaping layer **1024** is formed above the pole layer **1016**. A probe pole tip **1026** is formed above the flux shaping layer **1024** and extends to the air bearing surface (ABS) **1088** of the head **1000**. The shaping layer **1024** magnetically connects the magnetic flux from the back gap **1084** to the pole tip **1026**. The probe pole tip **1026** directs the flux into the media to perform the write function. The flux returns through the media to the return pole **1090**. The pole tip **1026** is preferably a ferromagnetic structure with a high magnetostriction, typically CoFe, NiFe, or laminated layers (CoFe, nonmagnetic layer, CoFe, nonmagnetic layer, etc.)

A nonmagnetic gap layer **1028** is formed above the probe pole tip **1026**. Exemplary materials for the gap layer **1028** are alumina or a nonmagnetic metal such as Rh, Ru, etc. As a note, there is a need for an insulator above the coil **1018** at the top surface **1098** to electrically isolate the coil from the ferromagnetic pole layers. A masking structure **1004** of conventional materials such as photoresist (oxide, nitride, silanated resist, etc.) is formed above the gap layer **1028**. The trailing shield **1002** is formed above the gap layer **1028** and the masking structure **1004**. The trailing shield **1002** is preferably constructed of a soft magnetic material, and should have a high magnetic moment. A preferred material for the trailing shield **1002** is NiFe and alloys thereof.

The throat height of the trailing shield **1002** is defined between the masking structure **1004** and the ABS. The trailing shield **1002** should have a throat height that is much less than the distance from the shaping layer **1024** to the ABS end of the pole tip **1026**. Preferably, the throat height of the trailing shield **1002** is less than about 100%, and more preferably, less than about 60% of the distance from the shaping layer **1024** to the ABS end of the pole tip **1026**.

Also, the thickness of the gap layer **1028** between the pole tip **1026** and the trailing shield **1002** is preferably roughly equal to the distance from the pole tip **1026** to the soft underlayer of the media, though a ratio of the gap layer **1028** thickness to the distance from the pole tip **1026** to the soft underlayer of the media can be in the range of about 1:2 to about 2:1. An illustrative thickness of the gap layer **1028** can be about 35 nm or less, but will scale with the dimensions of the pole tip **1026**, the dimensions being the track width and thickness of probe pole tip **1026**. Preferably, the thickness of the gap layer **1028** will be less than about 50 nm for a track width on the order of about 0.1 microns or less.

One advantage provided by the trailing shield **1002** is that because the bits in the media are written on the trailing edge of the pole tip **1026**, the trailing shield **1002** bends the magnetic flux lines. More particularly, the magnetic field that comes out of the probe pole tip **1026** enters the media at an off-normal angle, which may help write more stable bits in the media.

An outline of a perpendicular write head pole tip **1026** region is shown in FIG. **11** where the separation of the trailing shield **1002** and the pole tip **1026** is a gap of non-magnetic material. In order to form the trailing shield **1002**, a masking structure is formed

above the write gap **1028**. The height of masking structure (**HM**) is preferably substantially greater than the distance from the shaping layer **1024** to the ABS. For instance, the height can be greater than about 125% the distance from the shaping layer **1024** to the ABS. The reason for the tall height of the masking structure **1004** is to prevent leakage of the flux into the trailing shield **1002** before it reaches the ABS. A preferred height of the masking structure **1004** is about 0.5 microns or more.

The masking structure **1004** is preferably formed of a material that can remain in the head, such as an oxide, nitride, silanated resist (Si-containing resist) such as HSQ (hydrosilsesquioxide), etc. The mask is patterned and possibly shaped via reactive ion etching (RIE).

As shown in FIG. **12**, the trailing shield **1002** of NiFe other ferromagnetic material is deposited over and/or around the mask. For instance, if the trailing shield **1002** is a sputter deposited magnetic material, the trailing shield **1002** will encapsulate the masking structure **1004**.

FIGS. **13-14** depict a method of forming a trailing shield **1002** by plating. As mentioned above, the gap layer **1028** between the pole tip **1026** and trailing shield **1002** must be nonmagnetic, e.g., of alumina or some metal such as Rh, Ru, etc. Rh and Ru are preferred because they are very conductive, and the oxide of Ru is electrically conductive so it can be plated on.

Again, a masking structure **1004** is formed, preferably of a material that can remain in the head. See FIG. **12**. The structure is then placed in a plating solution and the trailing shield **1002** is formed by plating, resulting in the structure shown in FIG. **13**. The trailing shield **1002** may be overplated, such that it "mushrooms" over the edge of the

masking structure **1004**. While the trailing shield **1002** can be allowed to float, it is preferable to ferromagnetically connect the plated trailing shield **1002** structure to the rest of the head. As shown in FIG. **14**, the trailing shield **1002** is stitched to the head by a photolithographic lift off or, as shown, forming a return layer **1302** by plating more NiFe to the plated structure. The return layer **1302** extends back to the return pole **1016**. Note that the location and shape of the return layer **1302** can vary, but it is preferably stitched to the return pole **1016**.

There has thus been described a novel head structure and methods for forming the same. One advantage provided by the present invention includes allowing trailing shield edge definition to be defined with a thin resist process. Another advantage is that the edge of shield thickness is determined by the thickness of the transfer material. Yet another advantage is that the processes disclosed herein allow a thin trailing shield **1002** to be fabricated without damaging the pole tip **1026**. A further advantage is that the masking material is not present at the ABS surface.

While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.